Remote Sensing of Atmospheric Climate Parameters from the Atmospheric Infrared Sounder

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***Abstract*—This paper presents the standard and research products from Atmospheric Infrared Sounder (AIRS) and their current accuracies as demonstrated through validation efforts. It also summarizes ongoing research using AIRS data for weather prediction and improving climate models.**

Keywords-Atmosphere, Infrared, Weather Forecasting, Climate Models

I. INTRODUCTION

The Atmospheric Infrared Sounder (AIRS) is an ultraspectral infrared instrument on the EOS Aqua Spacecraft, launched on May 4, 2003. AIRS has 2378 infrared channels ranging from 3.7 um to 15.4 um and a 13.5 km footprint. AIRS, in conjunction with the Advanced Microwave Sounding Unit (AMSU) produces temperature profiles with 1K/km accuracy on a global scale, as well as water vapor profiles and trace gas amounts for CO_2, CO, SO_2, Ozone and CH_4. AIRS data are used for weather forecasting and studies of global climate change. The AIRS is a "facility" developed by NASA as an experimental demonstration of advanced technology for remote sensing and the benefits of infrared spectra to science investigations. The AIRS program has been an unqualified success with users worldwide including NOAA/NCEP who assimilate AIRS data into the operational models and have see significant positive impact to weather forecasts. More recently AIRS data are used by climate researchers interested in the role of water vapor in climate processes.

II. STANDARD PRODUCTS

A complete list of the AIRS/AMSU/HSB standard deliverable products are given in Table 1 [1]. The required RMS uncertainties of the products are listed, but in many cases the actual performance is much better. For example, the AIRS IR Radiances are only required to be 3% absolute, but we are finding them to be better than 0.3%.

TABLE I. AIRS STANDARD PRODUCTS

AIRS Standard Products	RMS Uncertainty*	Vertical Resolution	Horizontal Resolution
Radiance Products (Level 1B)			
AIRS IR Radiance	3% (0.3%)	N/A	15 x 15 km
AIRS VIS/NIR Radiance	20% (10%)	N/A	2.3 x 2.3 km
AMSU Radiance	.25 – 1.2 K	N/A	45 x 45 km
HSB Radiance	1.0 – 1.2K	N/A	15 x 15 km
Standard Core Products (Level 2)			
Cloud-Cleared IR Radiance	1.0 K	N/A	45 x 45 km
Sea Surface Temperature	0.5 K	N/A	45 x 45 km
Land Surface Temperature	1.0 K	N/A	45 x 45 km
Temperature Profile	1 K	1 km below 700 mb 2 km 700-30 mb	45 x 45 km
Humidity Profile	15%	2 km in troposphere	45 x 45 km
Total Precipitable Water	5%	N/A	45 x 45 km
Fractional Cloud Cover	5%	N/A	45 x 45 km
Cloud Top Height	0.5 km	N/A	45 x 45 km
Cloud Top Temperature	1.0 K	N/A	45 x 45 km

**** Radiance error defined as temperature error of Plank blackbody at 250°K. Achieved values in parentheses if different***

Level 1B Products include the calibrated radiances from the instruments. These products are obtained by applying the pre-flight and in-flight calibration data to the raw sensor counts.

Level 2 products are the "cloud-cleared" radiances, obtained by applying the microwave cloud clearing to normalize cloudy infrared radiances, Sea Surface and Land Surface Temperatures, Temperature and Humidity Profiles, Total Precipitable Water, and Cloud Parameters. All products are provided for every footprint of AIRS. Temporally aggregated and spatially subsetted versions of the standard data products are available in daily, weekly and monthly AIRS Level 3 products. All standard products are now available for the entire mission at the GSFC DAAC (http://daac.gsfc.nasa.gov).

In addition to these standard products, the AIRS has demonstrated its ability to produce several important "research products" including aerosol optical thickness, and concentrations of trace gases including CO, CH4, CO2, SO2, and Ozone. These products are still in the "research phase" and not available to the public. The infrared spectrum is rich in information and it is believed that the AIRS will retrieve many other trace gases not identified here.

III. CLIMATE QUALITY ASSESSMENT

The ability of AIRS to measure climate change in atmospheric parameters is based on the high stabilty of its calibrated radiances. The instrument employs a cryogenically cooled grating spectrometer that provides spectral separation and detection in a solid state system. Temperature control ensures that thermal fluctuations due to seasonal or diurnal changes in environmental loading on the spacecraft and instrument do not influence the calibration. Additionally a view of an on-board cavity blackbody and space view every scan line preserve the radiometric gain. Pre-flight calibration demonstrated better than 0.1K repeatability and 0.2K accuracy compared to NIST standards [2].

Post-launch observations of Sea Surface Temperature using the AIRS superwindow channel have shown [3] exceptional stability as shown in Figure 1. In this analysis, the surface temperature is determined from clear observations of the ocean surface using the AIRS super window channel at 2616 cm^{-1} which has less than 0.4 K atmospheric absorption. The sea surface temperature is compared to the RTG Network Surface Temperature. The slope of the difference is determined to be less than 16 mK/year. This stability is absolutely essential in producing products that can measure the small signatures associated with climate change.

A good example is provided by Aumann et. al [4]. in the observation of CO_2 using the AIRS calibrated spectra as shown in Figure 2. In this analysis the radiometric difference between CO_2 and background channels were calculated for clear (non-cloudy) fields over tropical ocean conditions. The differences were average over all fields acquired in a single day (red) and the corresponding night (blue). Results show the expected levels of CO_2 on a global scale with the expected 3ppmv/year increase due to anthropogenic influences. Although more rigorous methods have been used to observe CO_2 using AIRS data (see below), this

days from 20020100 daily median

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Figure 1. AIRS Stability as determined by the difference between th observed temperature at 2616 cm^{-1} and the Buoy RTG network [3].

demonstrates that the fundamental product of AIRS, the

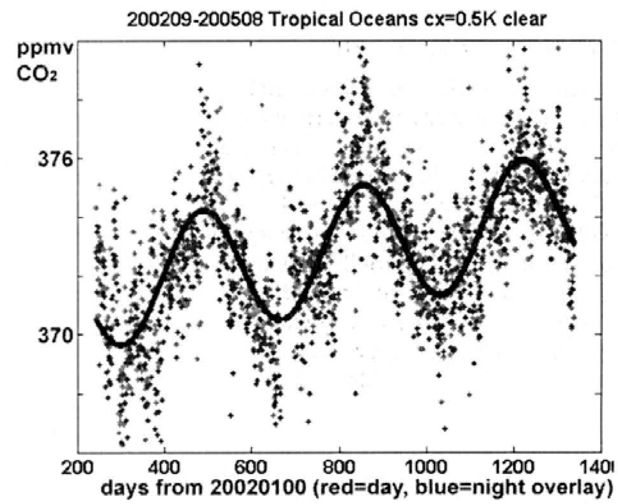

Figure 2. CO_2 derived from AIRS calibrated radiances since launch

calibrated radiances, are stable enough to observe small changes in atmospheric parameters that influence climate.

IV. WEATHER FORECAST IMPROVEMENT

Tests performed by the Joint Center for Satellite Data Assimilation (JCSDA), have seen a positive impact of the AIRS infrared radiances when assimilated into the NCEP forecast models [5]. The result was so good that the AIRS radiances are now currently being assimilated by the NCEP operational weather forecasting system. The system ingests one out of eighteen footprints and a subset of the channels. Results have shown an improvement in the 6day forecast score by an equivalent of 6 hours in the Northern Hemisphere. Although a significant forecast improvement has been found, the JCSDA is continuing to find improvement as they increase the number of footprints assimilated and the number of channels.

V. Climate Science using AIRS Temperature and Water Vapor Products

AIRS temperature and water vapor products are unprecedented in their coverage and accuracy of any space instrument to date. Table 1 presents the accuracies; essentially 1K/km vertical resolution for temperature on a 45 x 45 km grid, and 15% / 2km vertical resolution for water vapor also on a 45 x 45 km grid. Figure 3 shows the three-dimensional nature of the water vapor data from AIRS. The image shows surfaces of constant water vapor (Isohyets) over North America. The AIRS provides exceptional coverage with over 95% of the earth's surface imaged every day.

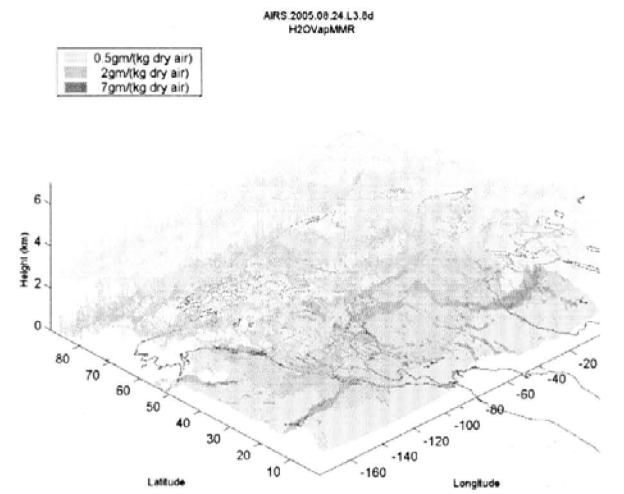

Figure 3. Isohyet surfaces of AIRS Water Vapor show more water vapor in the lower troposphere at mid latitudes, and less at high altitudes and near the poles. This image was created using the AIRS Level 3, 8 day water vapor product on August 24, 2005.

The vertical resolution of the AIRS data greatly improve the evaluation of the effects of water vapor transport from the boundary layer to the stratosphere on climate. This combined with the accuracy and coverage of the AIRS products have made them extremely useful for understanding process that affect global weather patterns including the Tropical Intraseasonal Oscillations (TISO) and the Madden Julian Oscillation (MJO).

Monsoon intraseasonal waves, or Tropical Intraseasonal Oscillations cause extreme periods of drought followed by extreme flooding during the boreal summer in Southern Asia. Current global circulation models (GCMs) either underestimate or over estimate the oscillation. . Members of the AIRS Science Team are studying the weather patterns that lead up to the TISO using AIRS data [6]. The AIRS data show much larger perturbations in the moisture in the troposphere than seen in models. AIRS data also show a drying of the boundary layer below the TISO convection most likely due to downdrafts. An increase in Sea Surface Temperature and a moistening of the boundary layer are observed prior to the TISO convection that could lead to a feedback effect destabilizing the atmosphere.

In a similar analysis, AIRS data were used to examine the Madden Julian Oscillation (MJO) [7]. The AIRS data show that the MJO temperature anomaly over the Indian Ocean and Western Pacific exhibits a trimodal structure; warm in the free tropopause (800 mb to 250 mb), and cold above and below; and the opposite as the pattern oscillates in time. The AIRS data also show that enhanced convection is preceeded by a warm and moist anomaly and followed by a cold and dry anomaly. This phenomenon is very similar to what is seen in the MISO study. In both cases, the data are in agreement with radiosondes and models, however, the AIRS data show much better accuracy and coverage than the NCEP models, particularly in water vapor amounts, thereby improving the correlation of the water vapor amounts and location and the TISO/MJO convection events.

VI. AIRS Trace Gas Products

The AIRS instrument has the ability to retrieve CO_2, CO, CH_4, O_3, and SO_2 and several other trace gases in the presence of clouds, daily, on a global scale. By providing trace gas amounts in addition to water vapor a total system view of the atmosphere can be made since the observations are made with global coverage and with vertical profile information. Although currently in the product generation and validation phase, scientists on the AIRS team are starting to use AIRS trace gas products to improve their parameterization of climate models.

A. Carbon Monoxide (CO)

Tropospheric CO abundances are retrieved from the 4.67 _m region of AIRS spectra as one of the last steps of the AIRS team algorithm. AIRS' 1600 km cross-track swath and cloud-clearing retrieval capabilities provide daily global CO maps over approximately 70% of the Earth each orbit. When combined, day and night and for two days, we get full coverage, as shown in Figure 4. This coverage is a major improvement over prior instruments and facilitates the study of global three dimensional transport of CO in the atmosphere. Preliminary validation indicates AIRS CO retrievals are approaching the 15% accuracy target set by pre-launch simulations [8].

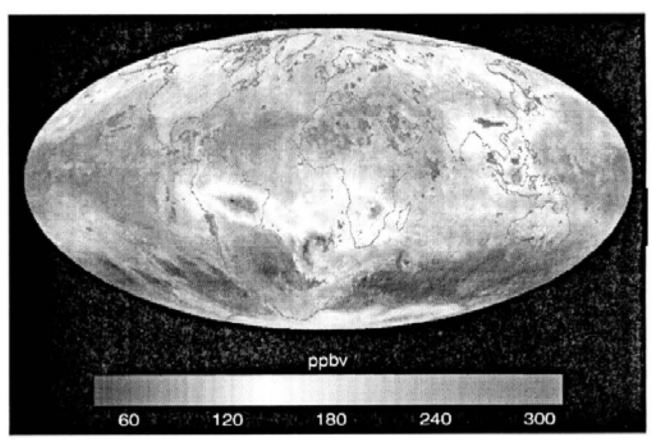

Figure 4. AIRS Carbon Dioxide for September 22-23, 2002

B. *Carbon Dioxide (CO_2)*

The most important trace gas retrieved by AIRS for the study of anthropogenic effects on climate is carbon dioxide. AIRS CO_2 retrievals use an analytical method for the determination of carbon dioxide and other minor gases in the troposphere from AIRS spectra [9]. The method is based on a general property of the total differential that enables retrieval of CO_2. We applied this method to derive the mixing ratio of carbon dioxide and compared the AIRS results to the aircraft flask measurements of carbon dioxide. Results show excellent agreement to ± 1.20 ppmv. This year we have generated the first global map of Carbon Dioxide (Figure 5) obtained from direct retrieval (no simulation). This map shows the mid tropospheric concentration of CO_2 (around 500 mb) for one week in January 2003.

Figure 5. AIRS CO2 for January 16-21, 2003

C. *Ozone*

AIRS total ozone measurements shown in Figure 6 are retrieved simultaneously with the temperature and water vapor products. Early results show good accuracy and coverage. AIRS uses infrared energy rather than reflected sunlight, as in the TOMS instrument and can retrieve ozone levels at night and over the poles during polar winter. Early validation results show agreement between AIRS and TOMS of better than 5% RMS [10].

VII. Conclusions

The Atmospheric Infrared Sounder, in conjunction with the AMSU instrument has produced exceptional climate quality atmospheric products. The products include three dimensional profiles of Temperature and Water vapor, Surface and Cloud products. The AIRS products are also unique in that they provide global coverage on a daily basis, facilitating the study of transport phenomenon of the atmospheric constituents. AIRS products have been used to improve weather prediction and study weather processes including the Tropical Intraseasonal Oscillation and the Madden Julian Oscillation. AIRS products, in particular water vapor, are also being used to improve parameterization of climate models. Finally, the AIRS trace gas research products have shown high accuracy and good coverage making them also attractive for climate modeling. All things considered, the AIRS/AMSU suite of instruments have made a valuable contribution to weather and climate prediction and will continue to do so through the end of the decade.

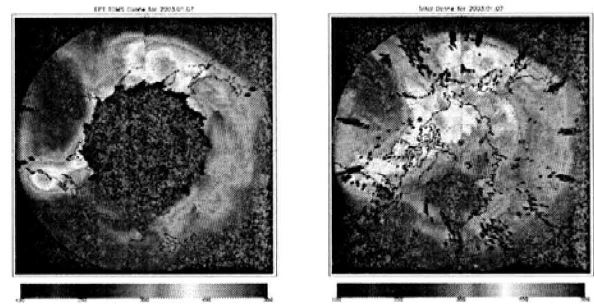

Figure 6. AIRS Ozone (Left), TOMS Ozone (Right) January 7, 2003 Black areas are where no data are available.

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